


# Live Feeling on Movement of an Autonomous Robot Using a Biological Signal

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**Abstract.** Using Khepera Simulator software, we developed an autonomous robot with a simple neural network by applying the skin conductance response of an observer who was watching the movement of the agent. First, we found that the signals were generated when the observer felt that the robot faced a crucial phase, such as hitting a wall. Therefore, we used the signals as errors that were back-propagated to the network in the robot. By questionnaires completed by the observer, the movement of this robot was compared with the movement of two other kinds of robots. In these other two robots, random signals or switch signals, which were turned on at the robot's crucial phase, were used as errors instead of the skin conductance responses. From the results, we found that the movement of the robot with biological signals was most similar to the movement of something alive in the three kinds of robots. It is thought that applications of biological signals can promote natural interactions between humans and machines.

## 1 Introduction

Recently, Nakatsu noted the relation between entertainment and communication [1]. He pointed out that the elements of the “sharing of experiences,” “physical experience and physiological experience” and “active immersion and passive immersion” are the commonality between entertainment and communication.

The effect of appearance and behavior on communication between a human and humanoid robot has also been studied [2, 3]. Minato et al. and Ono point out that the degree of intimacy to make natural communication is strongly affected by appearance and behavior, especially if a mutual entrained gesture and joint viewpoint is to be obtained by the relationship. As these facts make clear, the degree of intimacy depends on the contexts and their synchronization between two agents.

Khepera is an autonomous robot which moves depending on a sensor that measures its local environment. Since the structure of Khepera is much simpler than humanoid robots, it is hard to increase the degree of intimacy with this robot. However, we think that we can increase the intimacy with this robot if we take the contexts and their synchronization into the man-machine interface.

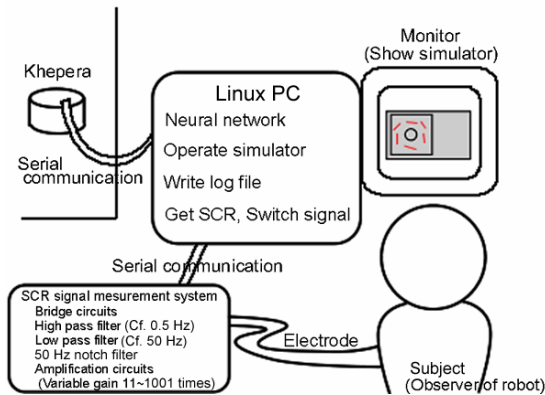
On the other hand, we have developed a novel computer game in which a player challenges him- or herself using the skin conductance response to make the player aware of his or her own agitation [4]. This game was developed as a paradoxical system in which the desire to win makes it more difficult to win. In this type of game, players find themselves uncontrollable after viewing their biological signals. In other words, a kind of self-reference system is constructed. It is thought that this is a typical example of taking the contexts and their synchronization into a man-machine interface.

Electrical signals detected from the living body are objective and quantitative data reflecting the psychological states and physiological functions of the human body [5]. For example, the biological signal used in lie detector testing is the skin conductance response (SCR), in which changes in the conductance on the skin surface are induced by sweating due to mental agitation, surprise and excitation [6].

Therefore, we tried to produce a novel robot by taking the SCR signal of a human observing the robot into the robot to increase the intimacy between the human and the robot. Then, we assessed the intimacy with the robot.

## 2 System and Materials

Instead of a real robot, we used Khepera Simulator (Olivier Michel Simulator Package version 2.0: a freeware mobile robot simulator written at the University of Nice Sophia-Antipolis by Olivier Michel. This freeware is downloadable from the World Wide Web at <http://wwwi3s.unice.fr>), because it is adequate for our work and also because it makes it easy to watch the robot movement and record its trajectory. Figure 1 shows the diagram of the system.



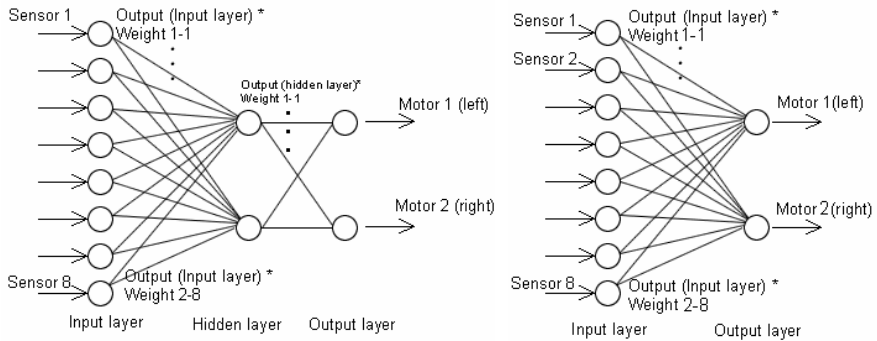
**Fig. 1.** The diagram of the system. This study used Khepera Simulator, by which the virtual robot moves in a PC monitor. The movement of Khepera in the PC monitor is affected by the SCR of the subject who is watching the movement. The SCR signal is detected by the SCR signal measurement system and is sent to the Linux PC.

## 2.1 SCR

The SCR occurs due to a change in conductance on the surface of the skin due to sweating [5, 6]. Since eccrine sweat glands are most dense on the palm of the hand and sweating is an autonomic response that can be triggered by emotional stimuli [5, 6], the palm is an ideal site from which to obtain measurements of psychophysical activity using the SCR. The player holds a controller in one hand and the palm of the other hand provides the SCR via two electrodes (disposable electrocardiogram electrode J Vitrode, Ag/AgCl solid-gel tape, Nihon-Koden, Tokyo). The signal was amplified by a SCR sensor and fed into the PC through an A/D converter.

## 2.2 Neural Network and Diagram

The movement of the robot is generated by the simple back propagation neural networks shown in Figure 2. Khepera has eight optical sensors for detecting obstacles and two motors for moving. Therefore, the network basically has eight neurons corresponding to each sensor on the input layer and two neurons corresponding to each motor on the output layer. Also, a hidden layer is introduced when the values from the sensors are high. The two motors act depending on the 21-step values (from -10 to 10), which are linearly proportional to the value of each output layer.



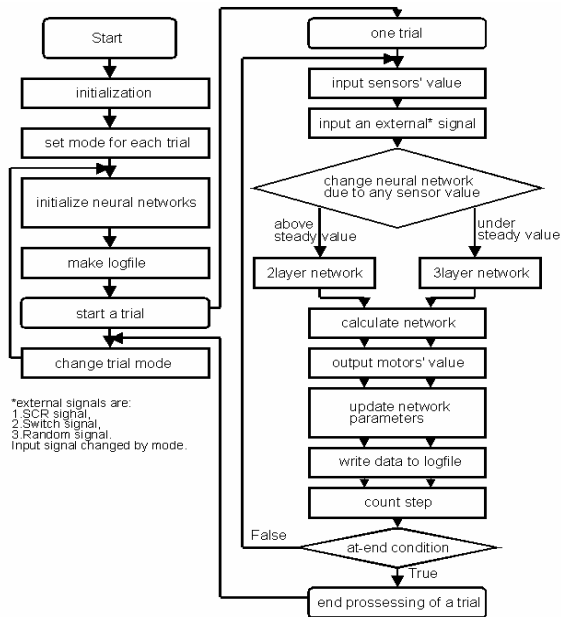
**Fig. 2.** Three-layered (left) and two-layered (right) neural networks used in the robot

The output weight of each neuron,  $w_{ij}$ , is determined by the next formulae.

$$w_{t+1ij} = w_{tij} + \Delta w_{ij} \quad (1)$$

where

$$\begin{aligned} \Delta w_{ij} &= \varepsilon \cdot \text{biosignal} \quad (\text{using biosignal}) \\ \Delta w_{ij} &= \varepsilon \cdot \text{switchsignal} \quad (\text{using switch signal}) \\ \Delta w_{ij} &= \varepsilon \cdot \text{random} \quad (\text{using random signal}) \end{aligned} \quad (2)$$



**Fig. 3.** The flowchart of the program in Khepera. This very simple system was employed to view the pure effect of the biological signal.

The initial weight is determined randomly. This system is not the usual neural network system, because the system does not have a solution, goal and converged state. The three above equations (2) are the errors for the usual neural network system. One equation is selected from the equations depending on the experimental condition listed below. SCR signals are fed to the network by this equation. Figure 3 shows the flowchart of this system. In this research, such a simple and unusual system is used for revealing the difference between the system using SCR and the systems using the other signals.

### 3 Experiments

We focused on how to accept the movement of the robot using the subject's observation of the robot. We conducted an experiment to compare the intimacy of the robot using SCR with that of the robot using a random or switching signal.

The movement of the robot developed in the present study was observed under various conditions for 60 seconds by subjects 20 to 23 years of age. The seven instructions listed in Table 1 were given to each subject for every trial. The SCR of the subject and the trajectory of the robot were recorded while the subject observed the movement. After each trial, a subjective assessment of feeling of the robot, listed in Table 2, was performed by the subject.

**Table 1.** Instructions given to each subject for every trial

Trial	Instruction	Signal used
1st	Just watch the movement of the robot.	random
2nd	Just watch the movement of the robot.	SCR
3rd	Your SCR signal will be sent to the robot. Just watch the movement of the robot.	SCR
4th	Your SCR signal will be sent to the robot. Just watch the movement of the robot.	random
5th	Your switching signal will be sent to the robot. Turn it on at the robot's crucial phase while you watch the movement of the robot.	switch
6th	Your switching signal will be sent to the robot. Turn it on at the robot's crucial phase while you watch the movement of the robot.	SCR
7th	Your switching signal will be sent to the robot. Turn it on at the robot's crucial phase while you watch the movement of the robot.	random

**Table 2.** Items to be assessed by the subject. The subject chooses a point on a scale of 1 to 6 for each question.

	Item to be assessed	(less) Point (much)
Question 1	How much did the robot move against your intention?	1 2 3 4 5 6
Question 2	How much did you feel that the movement of the robot looks like living matter's movement?	1 2 3 4 5 6
Question 3	How much did you feel intimacy with the robot?	1 2 3 4 5 6

## 4 Results and Discussions

First, the relations between the trajectory of the robot and the SCR were investigated. Figure 4 shows a typical example of a resulting trajectory (blue line). A large SCR was observed at the position marked with orange dots. The red squares indicate obstacles put out by the experimenter. The start point of Khepera's movement was the center point of this field.

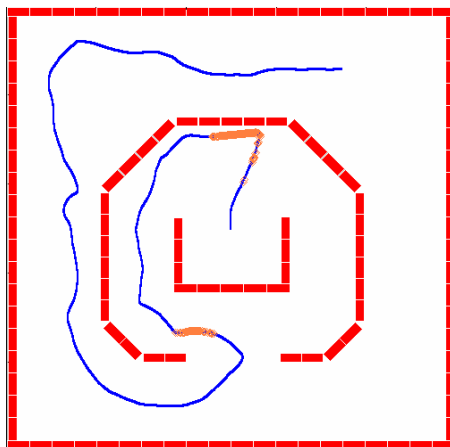
In this record, for example, there are two domains in which the SCR was generated. The first domain can be interpreted as a sign of the subject's anxiousness about Khepera hitting the wall. The second domain can be interpreted as the subject's frustration over worrying about the never-ending cycle.

From the results, we found that the SCR signals were generated when the subject felt that the robot faced a crucial phase. The SCR signal made the movement pattern of Khepera smooth, safe and dynamic.

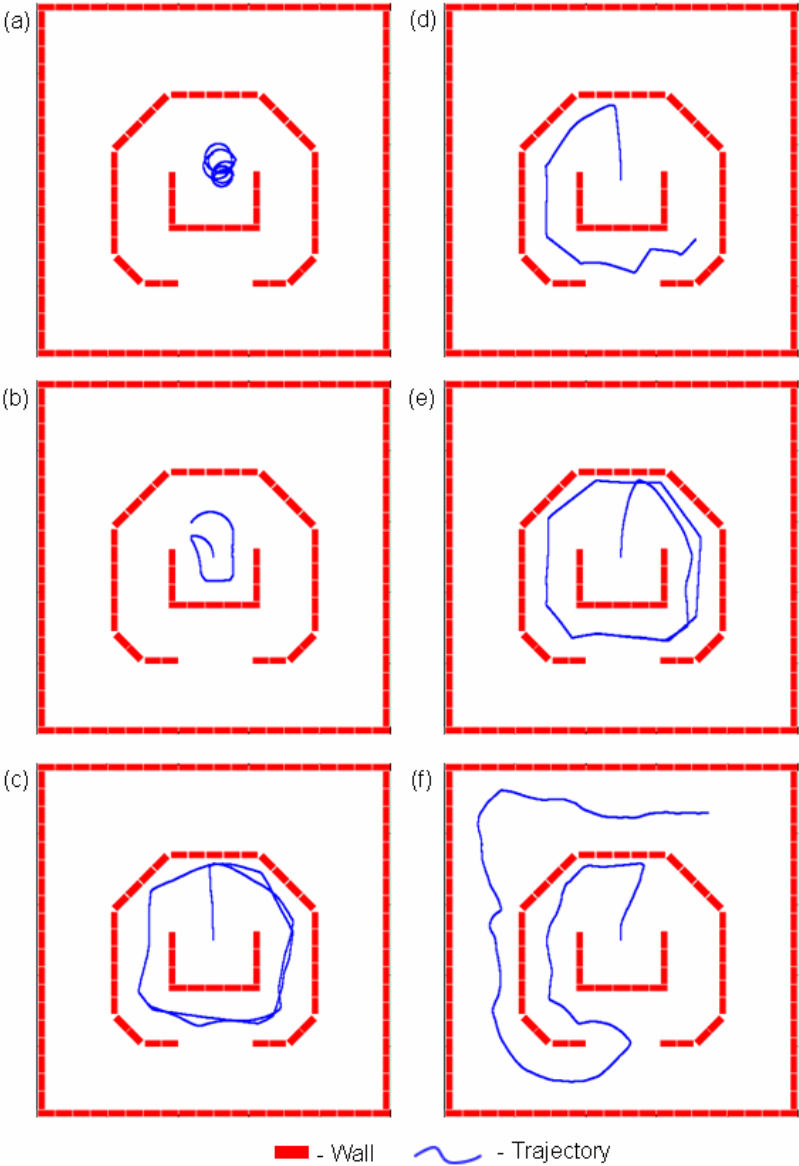
Figure 5 shows examples of the trajectory (blue lines) of two kinds of robots. The trajectories from (a) to (c) are typical results of the robot using random signals instead of SCR. The trajectories from (d) to (f) are typical results of the robot using SCR.

The area of the trajectories of the robot using the SCR signals was wider compared with that of the robot using the random signals. The robot using the SCR can move smoothly because it can receive information of the whole view, even though this information is gained indirectly.

Figure 6 shows the result of the assessment completed by the subjects. The result shows that the answers to Question 2 and Question 3 tended to be similar. Intimacy has a deep relationship with the live feeling.



**Fig. 4.** The typical resulting trajectory (blue line) of the robot and the typical position (orange dots) at which the SCR of the subject was large. The SCR occurred when the subject felt danger or frustration regarding the movement of the robot.



**Fig. 5.** Examples of the trajectories (blue lines) of two kinds of robots. The trajectories from (a) to (c) are typical results of the robot using random signals instead of SCR. The trajectories from (d) to (f) are typical results of the robot using SCR. The red squares indicate the walls put out by the experimenter.

There are some noteworthy facts apparent in Figure 6. First, the assessment points of Questions 2 and 3 at the 2<sup>nd</sup> trial are much larger than that at the 1<sup>st</sup> trial. In both the

1<sup>st</sup> and 2<sup>nd</sup> trials, the conditions were the same, except for the signal to determine  $\Delta w_{ij}$  in the neural network. Also, the subjects did not know the difference. This means that the robot using SCR seems to be alive. However, the assessment points of Questions 2 and 3 at the 3<sup>rd</sup> trial are smaller than that at the 2<sup>nd</sup> trial. And, the points of Question 1 increased at the 3<sup>rd</sup> trial. This means that the subjects felt that the robot moved against their intention by knowing the fact that their SCR signals were reflected to the robot.

Second, at the 5<sup>th</sup> trial, the points of Question 1 became max and also the points of Questions 2 and 3 were not so high. However, the points of Question 1 curiously became low at the 6<sup>th</sup> trial.

From these results, it is thought that applications of biological signals bring a live feeling to the robot and increase the degree of intimacy with the robot. And the knowledge about the mechanisms of the system and the applications of the switch tend to bring strong expectations for system control, which also causes a disappointing result.

Therefore, it is thought that SCR has the following interesting features for natural communication, which is important for entertainment. First, SCR can take the contexts and their synchronization into a man-machine interface. Second, SCR can be obtained subconsciously. This factor makes the system unpredictable and alive.

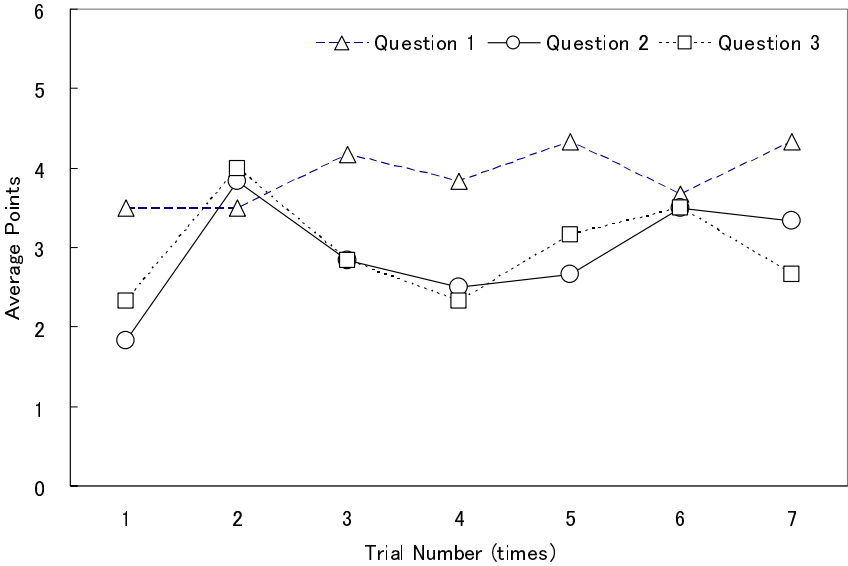


Fig. 6. The resulting average points of the assessments done by the subject after each trial

## 5 Conclusion

A novel autonomous robot using the observer's SCR was developed in this study. This robot revealed some important features for natural communication between man and machine. These features correspond to the important features for entertainment computing.



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